Holz als Roh- und Werkstoff 55 (1997) 175–182 © Springer-Verlag 1997

Radially sawn timber

The influence of annual ring orientation on crack formation and deformation in water soaked pine (*Pinus silvestris L*) and spruce (*Picea abies Karst*) timber

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This work describes deformation and crack formation in sawn timber of pine and spruce after first drying and subsequent cycles of resoaking in water and drying. The influence of annual ring orientation and the occurrence of juvenile wood was determined. In addition, the influence of compression wood, annual ring orientation at the edges of the cross section, the position of the board surface in relation to the pith, and the condition of the board surface i.e. whether wet or dry during resoaking were studied.

When timber is exposed to repeated cycles of wetting and drying, warp, viz spring, bow, twist and cup, increases and is greater after the first cycle. The influence of annual ring orientation on spring, bow and twist depends on the type of deformation and on the kind of wood. Generally, the results indicated that timber with vertical and semi (half) vertical annual rings show less deformation (mean values) than plain sawn timber and timber containing pith. Cup is mainly caused by transverse anisotropy and is strongly influenced by the radius of the annual ring. Therefore, timber with vertical annual rings do not show any cup.

Spring, twist and, especially bow are strongly influenced by compression wood. Large amount of compression wood in sawn timber increases such deformation.

The distance between sawn timber in the log and the pith with surrounding juvenile wood is of vital significance for cracking. During moisture cycling, the amount of boards that develop cracks increased irrespective of their prior location in the cross section of the stem.

Timber sawn from near the pith or distinctly containing pith has a higher relative crack length compared to timber sawn away from and lacking pith. In timber exposed to repeated cycles of wetting and drying the crack length increases irrespective of its prior location in the stem.

Radial gesägtes Schnittholz – Einfluß der Jahrring-Orientierung auf Rißbildung und Verwerfung von Kiefern- und Fichten-Schnittholz nach wiederholtem Trocknen und Befeuchten

In diesem Beitrag werden Verwerfung und Rißbildung von Kiefern- und Fichtenschnittholz nach dem ersten Trocknen und mehreren Feuchtezyklen beschrieben. Der Einfluß der Jahrring-Orientierung und des Anteils an juvenilem Holz wurde bestimmt. Zusätzlich wurden untersucht der Einfluß des Druckholzanteils, der Jahrring-Orientierung an den Hirnflächen, die Position der Bretter in Bezug auf die Markröhre sowie die Bedingungen der Brettoberflächen (ob sie während des Feuchtezyklus feucht wurden oder trocken blieben). Die Verwerfungen (Krümmung, Flügligkeit, Schüsseln) verstärkten sich nach dem ersten Feuchtezyklus. Der Einfluß der Jahrring-Orientierung hängt von der Art der Verwerfung und von der Holzart ab. Allgemein zeigen Bretter mit stehenden oder halbstehenden Jahrrringen im Mittel geringere Verwerfungen als solche mit liegenden Jahrringen oder mit Markröhrenanteil. Schüsseln entsteht bevorzugt bei anisotropen Querschnitten und hängt stark vom Radius der Jahrrringe ab. Bei Brettern mit stehenden (vertikalen) Jahrrringen tritt Schüsseln nicht auf. Längsverwerfung, Flügligkeit und vor allem Krümmung werden stark vom Anteil an Druckholz beeinflußt. Für die Rißbildung ist der Abstand des Brettes von der Markröhre und dem juvenilen Holz ausschlaggebend. Während der Feuchtezyklen ist der Anteil der Bretter mit Rißbildung unabhängig von ihrer ursprünglichen Position im Stammquerschnitt.

1
Introduction

Cracks and major deformations can make boards unusable for some applications. Various kinds of deformation in sawn timber, usually referred to as warp, can be a consequence of primary stresses in the log, so-called growth stresses, or they may arise during processing, especially when drying timber. If these stresses, which are a consequence of shrinkage, become greater than the fracture strength of the wood material, cracks will develop in the timber.

The anisotropic, hygroscopic and non-homogeneous nature of wood creates feasible conditions for warp. The most troublesome characteristic of wood in structural applications and furniture manufacture, is its hygroscopicity.

During late 1950's Armstrong and Kingston (1960) observed that when small wood samples are subjected to flexural load and exposed to cyclic humidity variations, the deformation increased dramatically compared to when constant climatic conditions were used. Similarly recovery after unloading was accelerated by varying humidity. This phenomenon is usually referred to as mechano-sorption.

The influence of juvenile wood on warp has been investigated by several researchers, including Hallock (1965), Balodis (1972), Danborg (1990) and Perstorper et al. (1995). Their results show that occurrence of juvenile wood normally increases warp in softwood.

Timber with vertical annual rings, i.e. radially sawn timber, undergoes no, or very small changes in shape because the sides of the timber are parallel to the main directions of the wood.

A new method of sawing, Star-sawing, to produce industrial pith-free timber with vertical annual rings and without juvenile wood has been proposed (Sandberg

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The author wishes to thank Nils & Dorthi Troëdsson Foundation for financial support in the execution of this work.

1996a). It has been shown that timber produced with this method is less subjected to cracking, especially when the timber is exposed to moisture variation, than timber produced with conventional sawing methods (Sandberg 1996b).

The objectives of this work are to study the influence of annual ring orientation, pith and juvenile wood on warp and to investigate macroscopic cracks induced in timber exposed to moisture changes.

2 Materials and methods

2.1 Log selection and sawing

Six butt logs of Scots pine (*Pinus silvestris L*) and seven of Norway spruce (*Picea abies Karst*) were randomly selected from a local sawmill in northern Sweden. The logs were oversized which in this case means that the top diameter exceeded 35 cm. Only timber of U/S (the best quality) and fifth quality (V) was included in the study. The down grading of the timber from U/S to quality V is mainly due to knot distribution in the log. The logs were presumed to be representative for oversized logs in the region. Before sawing, the cross section of each log was colored in an area with a radius of 30 mm around the pith. This coloured area was later used to detect the distance from the pith for each board, and was chosen as a borderline between juvenile and mature wood as far as slowly grown wood from northern Sweden is concerned.

To obtain boards with different annual ring orientations and different distances from the pith, the logs were sawn according to both "through-and-through" sawing and "Star-sawing". Triangular profiles were not included in this investigation. To avoid one annual ring orientation being sawn from only one, or only a few logs, half of each log was sawn through-and-through and the other half in the Star-sawing pattern (Figure 1). The boards were kiln dried using a conventional drying program to a moisture content of 18 ± 3%. All the boards were sawn with a cross section dimension of 50 by 100 mm.

2.2 Density and moisture content determination

When the test was finished, three two-centimeter-long cross sections were cut from each board, one at each end and one in the middle of the board. These specimens were used to determine the density and the moisture content. The specimens were free from knots and wood near knots, but compression wood may be present in some specimens. The moisture content was defined as the ratio: of the mass of water in the specimen to the dry weight of the specimen.

2.3 Wetting cycles

The boards were exposed to three cycles, lasting 20 days and nights, of wetting and drying. Before the first wetting, the weight of the boards was determined. In the wetting phase the boards floated freely for 30 minutes in a tray with water. Then, before being weighed, the boards were placed in a frame for 15 minutes with the wet side up to let free water on the surface penetrate into the wood or evaporate. Thereafter, the boards were dried for 20 days and nights at a temperature of 21 ± 1 °C and 39 ± 5% RH. The same surface was soaked in each wetting phase. Before the test was started the boards were conditioned for two weeks at the same climate as mentioned above.

2.4 Warp measurement

Warp was measured after every drying cycle. Cup was measured at five locations along the length of the board: five cm from each end of the board and at three equidistant locations between these two end measuring points. Crook, bow and twist values were measured over the entire length of the board and the values were later reduced to equal lengths of three metres according to Morén (1987). Figure 2 illustrates the principles for measuring warp used in this investigation.

For analysis, the boards were divided into four groups according to the annual ring orientation in the cross section. The first group contains boards in which pith was enclosed in the cross section, in the whole or in a part of the total length of the board. The other three groups contained boards with horizontal, semi-vertical and vertical annual rings. Figure 3 illustrates examples of timber with different annual ring orientations. Vertical annual rings exist in the cross section when the angle between a tangent to an annual ring at half of the thickness of the board and the face side is between 60 and 90 degrees (Sandberg 1995) (Figure 4). Similarly, boards with horizontal annual rings exist when the same angle was between 0 and 30 degrees. When the angle was between 30 and 60 degrees the boards are said to have semi-vertical annual rings.

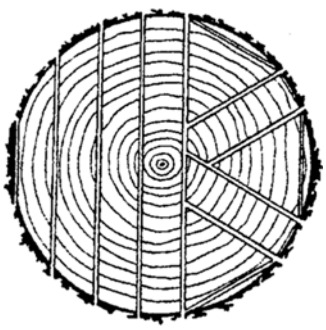


Fig. 1. The sawing pattern used in the investigation. Half the log was sawn through-and-through and the other half using a Star-sawing pattern
Bild 1. Einschnittmuster der Versuchsproben. Eine Hälfte des Rundholzes wurde sternförmig aufgesägt

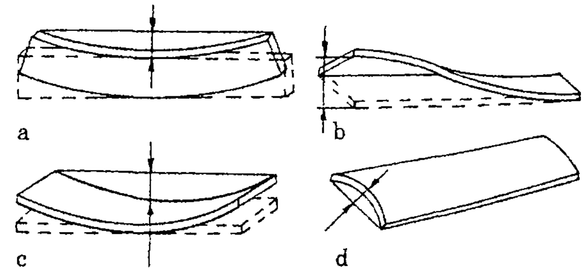


Fig. 2a–d. Definition and measuring of warp: (a) crook; (b) twist; (c) bow; and (d) cup
Bild 2a–d. Definition und Messung der Verwerfung: (a) Längsvewerfung; (b) Verdrehung (Flüglichkeit); (c) Krümmung; (d) Schüsseln

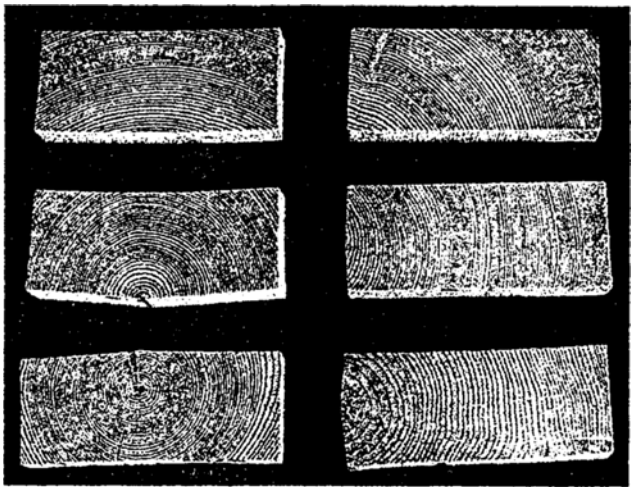


Fig. 3. Examples of different annual ring orientations in the cross sections of boards
Bild 3. Beispiele für verschiedene Jahrring-Orientierungen an den Hirnflächen der Bretter

2.5
Determination of compression wood

Compression wood has a much greater longitudinal shrinkage than normal wood (Timell 1986). This will cause more warp in boards containing a greater proportion of compression wood. A common complication is how to determine the proportion of compression wood and how to find a fast and reliable measure. One of the best measures of compression wood is through the combination of volume proportion and location of compression wood in the board. Such methods are however very time consuming. It is more convenient to select parts of the board where the occurrence of compression wood may be determined. In doing so, it is important to select samples which are representative of the board. When warp is investigated, it is also important to avoid small local areas of compression wood, for example around knots, that may be of minor importance for the global deformation of the board. It should, however, be noted that shrinkage of knot wood and wood surrounding knots may to a large extent influence the total warp of the board. In this investigation, the specimens used to determine density have also been used to detect the presence of compression wood.

The boards were classified into four classes, C0–C3, with respect to the occurrence of compression wood in three cross sections cut from each board. Class C0 has no compression wood in the cross sections; class C1 has visible compression wood in one of the three cross sections; class C2 in two and class C3 in all three cross sections.

As mentioned earlier, the specimens were cut free of knots and local compression wood areas beneath knots were avoided as far as possible.

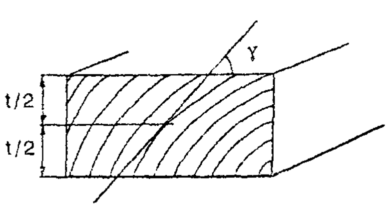


Fig. 4. Definition of annual ring orientation
Bild 4. Zur Definition der Jahrring-Orientierung

2.6
Crack measurement

The total length of visible cracks on each surface of the boards was determined after the described conditioning period and after the last wetting cycle.

2.7
Statistical methods

A common complication when analysing experimental results in wood is that the values do not have a normal distribution. Söderström (1990) has shown that the assumption of normal distribution when analysing lengths and areas of cracks is poor. The results of the present investigation have also indicated that warp is not normally distributed. For this reason, a non parametric test was used when the results for the test groups were evaluated as mean values (Montgomery 1991). In this statistical method, normally distributed test parameters are not necessary. The tendency of a test group (boards with different annual ring orientations and distances from the pith) to show a special property (warp or cracking) was tested using a homogenity test (Blom 1991). Unless otherwise mentioned, a confidence interval of 0.95 has been used in all the tests.

3
Results and discussion

3.1
Density

Table 1 shows the mean values for dry density of the boards and the density separated into mean values for root, middle and top parts of the boards. The density values are representative for butt logs from northern Sweden. It should be noted however that the density of pine is the least at top end and increases towards the butt end of the log. In spruce this density difference is negligible.

Normally, compression wood has a higher density than normal wood (Timell 1986). When specimens of compression wood were excluded from the samples, no difference in the density values occurred. This fact suggests that the fraction of compression wood in the specimens was relatively low. Therefore the influence of compression wood was slight.

3.2
Moisture cycling

Figure 5 shows the mean values of the moisture content variation in the boards during the test. The moisture content was determined for three cross sections after the last wetting cycle. It is assumed that the mean value of the moisture content for these three cross sections was equal to the mean value of the moisture content of the board. The moisture content was then determined before and after each wetting phase.

Table 1. Dry Density (Kg/m^3) of boards in the investigation. Root, middle and top reflects the location of the specimens in the board. The mean value of these three measurements is also given.
Tabelle 1. Rohdichte der Versuchsbretter in verschiedenen Brettpositionen sowie deren Mittelwert.

	Root	Middle	Top	Mean
Pine	476	412	389	426
Spruce	353	350	351	351

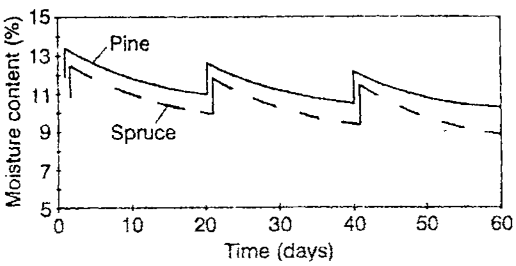


Fig. 5. Variation of moisture content in the boards during the test
Bild 5. Verlauf der Holzfeuchte in den Brettern während der Versuche

As shown in Figure 5, the moisture content during the wetting phases increases only a few percent. It should be noted that the variation in moisture content in those parts of the boards which were in contact with water was much higher.

3.3
Influence of annual ring orientation and wetting on warp

Figure 6 shows the measurements of warp such as crook, bow, twist and cup for the boards during three cycles of wetting and drying. According to the annual ring orientation in the cross section, the boards are divided into four

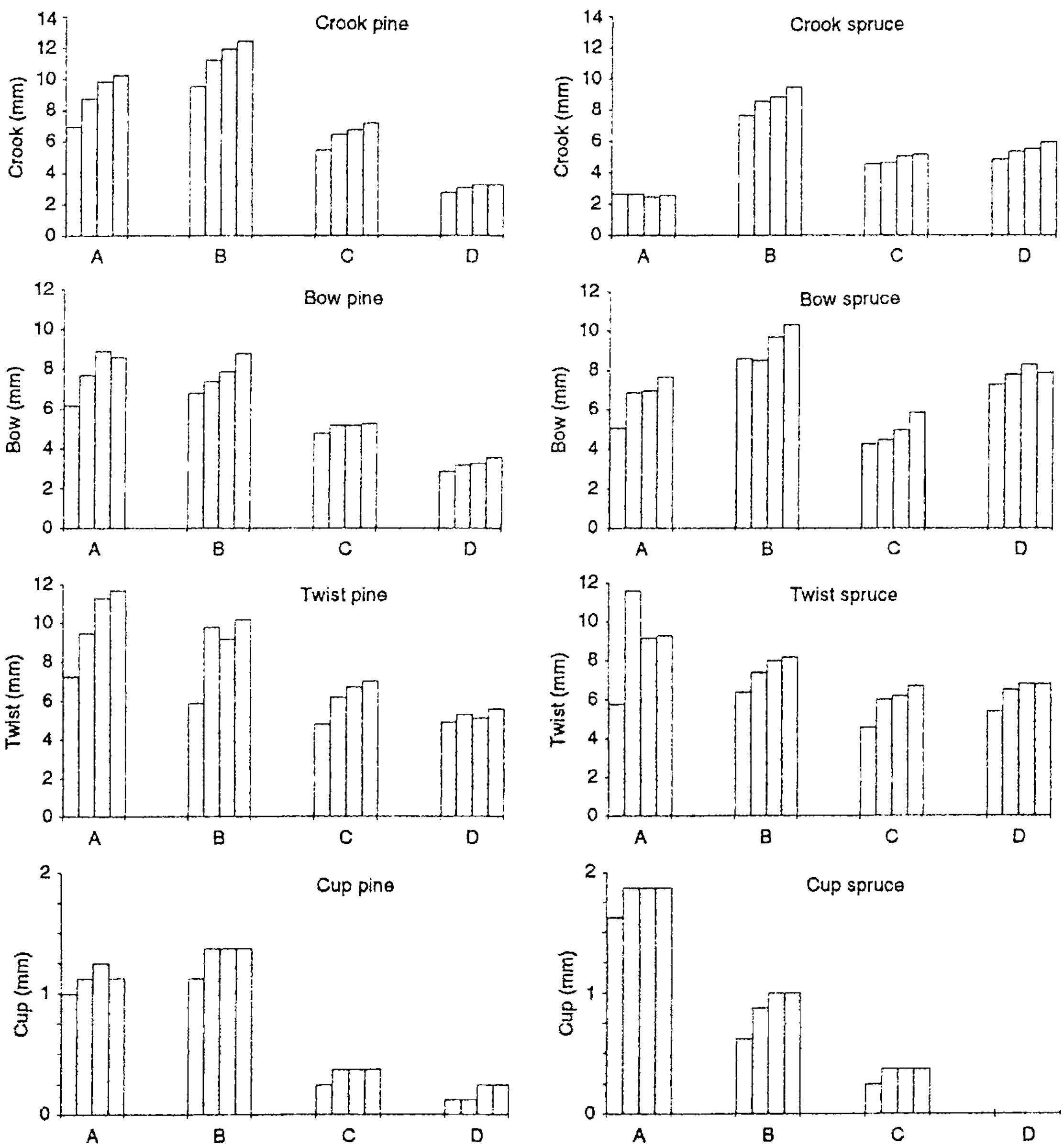


Fig. 6. The influence of annual ring orientation (A–D) on warp in boards of pine and spruce during three cycles of wetting and drying. The first bar reflects warp before wetting, the second bar warp after the first cycle etc. A – pith enclosed in the cross section, B – horizontal annual rings, C – semi-vertical annual rings, D – vertical annual rings
Bild 6. Einfluß der Jahrring-Orientierungen (A–D) auf die Verwerfung in Kiefern- und Fichtenbrettern im Verlauf von drei Feuchtezyklen. Der erste Balken entspricht jeweils der Verwerfung vor dem Befeuchten, der zweite Balken nach dem ersten Zyklus usw. A – Markröhre im Querschnitt enthalten; B – horizontale (liegende) Jahrringe; C – halb-vertikale Jahrringe; D – vertikal (stehende) Jahrringe

groups. Group A has the pith enclosed in the cross section in all of, or in a part of, the length of the board. Groups B, C and D correspond to the horizontal, semi-vertical and vertical annual rings, respectively. Diagrams in Figure 6 have four bars for each group. The first bar represents the warp before the wetting cycle, while the second to fourth bars correspond to warp after one to three cycles of wetting and drying.

3.3.1 Crook

In both pine and spruce except for spruce group A, crook increases for each cycle of wetting and drying, independent of the annual ring orientation. Crook for pine with vertical annual rings (group D) is lower than for the other groups, but this difference is not significant. Due to great scattering of the crook values, no significant differences were found between groups A to D. The relatively low crook for spruce in group A may reflect the high number of cracks in these boards (see section 3.5).

In both pine and spruce, no correlation was found between the distance from the pith and the crook. This was expected, as no consideration was given on how the edges of the boards were oriented in relation to the pith. In spruce, boards with crook (measured as shown in Figure 2) on the edge oriented towards the pith demonstrated significantly more crook than boards where the crook was oriented in other directions. This indicates that juvenile wood has an influence on warp. The greater crook for pith-associated boards is consistent with several studies, for example Kloot et al. (1959) and Perstorper et al. (1995).

3.3.2 Bow

Independent of the annual ring orientation of the boards, bow increased in both pine and spruce during moisture cycling. Before the first cycle of wetting and drying no difference in bow between the groups in pine was found. When boards were resoaked, bow for the boards with vertical and semi-vertical annual rings (groups C and D) was significantly lower than those with horizontal annual rings and pith. Spruce did not show any significant differences between groups A to D. When both pine and spruce are considered, the only difference was found in group D, where spruce has significantly more bow than pine.

When the boards were resoaked in each cycle, the same face was in contact with water. The influence of resoaking on bow is illustrated in Figure 7. Before resoaking, the bow was of the same size for the wetted and the non-wetted face, for both pine and spruce. During the wetting cycles the behaviour of the boards was completely different for pine and spruce.

Pine demonstrates a slight increase of bow, regardless if it occurs on the wetted surface or not. There was no significant difference in bow between the boards as far as the wetted and the non-wetted face was concerned. In spruce, the boards on the wetted face showed an increase of bow during moisture cycling. On the other hand the boards with a non-wetted face showed a decrease of bow. This means that bow always increased on the wetted face.

3.3.3 Twist

In the same way as for crook and bow, twist increases when the boards are exposed to cycles of wetting and drying. The increase in twist was greatest for boards in group A, which may be considered natural as these boards contain pith. The level of twist was expected to be greater for boards in group A compared to groups B–D. The relative low twist in the boards belonging to group A may be a consequence of a higher number of cracks (see section 3.5) in these boards. Several researchers (e.g. Mishiro et al. 1988; Perstorper et al. 1995) found that twist was more pronounced in boards taken near the pith than in boards sawn distant from the pith. This study, however, shows no significant differences between twist in groups A–D or between pine and spruce.

3.3.4 Cup

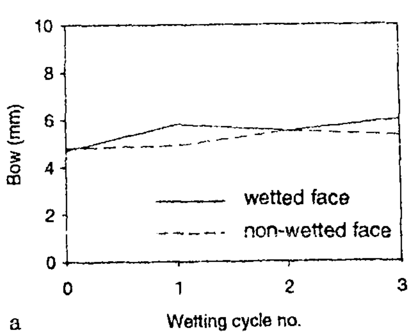
Cup was measured at five locations in each board. Here, the greatest of these five measurements was used to determine cup. Since the width of the boards was 100 mm, the cup was small and only a couple of mm. The change of cup during moisture variations was even smaller and was hard to detect with the measurement accuracy used.

As shown in Figure 6, cup was highest for boards in groups A and B as a consequence of the anisotropic nature of the wood material and the curvature of the annual rings. Thus boards with horizontal annual rings sawn near the pith usually have more cup than boards with the same annual ring orientation sawn at the periphery of the log.

Pine with vertical annual rings also showed cup. That may be explained by the annual ring orientation at the butt end of some of the boards which were not vertical due to buttness. When the maximum value were used for cup, the cup at the butt end will represent the board.

3.4 Influence of compression wood on warp

In Figure 8 crook, bow and twist are shown for the four different levels (C0–C3) determined for compression wood. In pine the number of boards in levels C1–C3 was



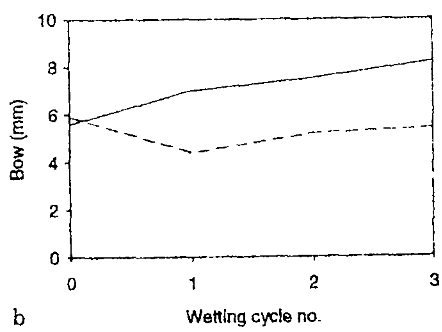


Fig. 7a and b. Mean values for bow in pine (a) and spruce (b) when consideration has been taken of the wetted surface. Measure 0 was before wetting and measure 1–3 after the first to the third wetting cycle

Bild 7a und b. Mittlere Krümmungen in Kiefern- (a) und Fichtenbrettern (b) nach zyklischem Befeuchten der Obrfläche. Meßpunkte 0: vor dem Feuchtezyklus; 1–3: nach dem ersten bis dritten Zyklus

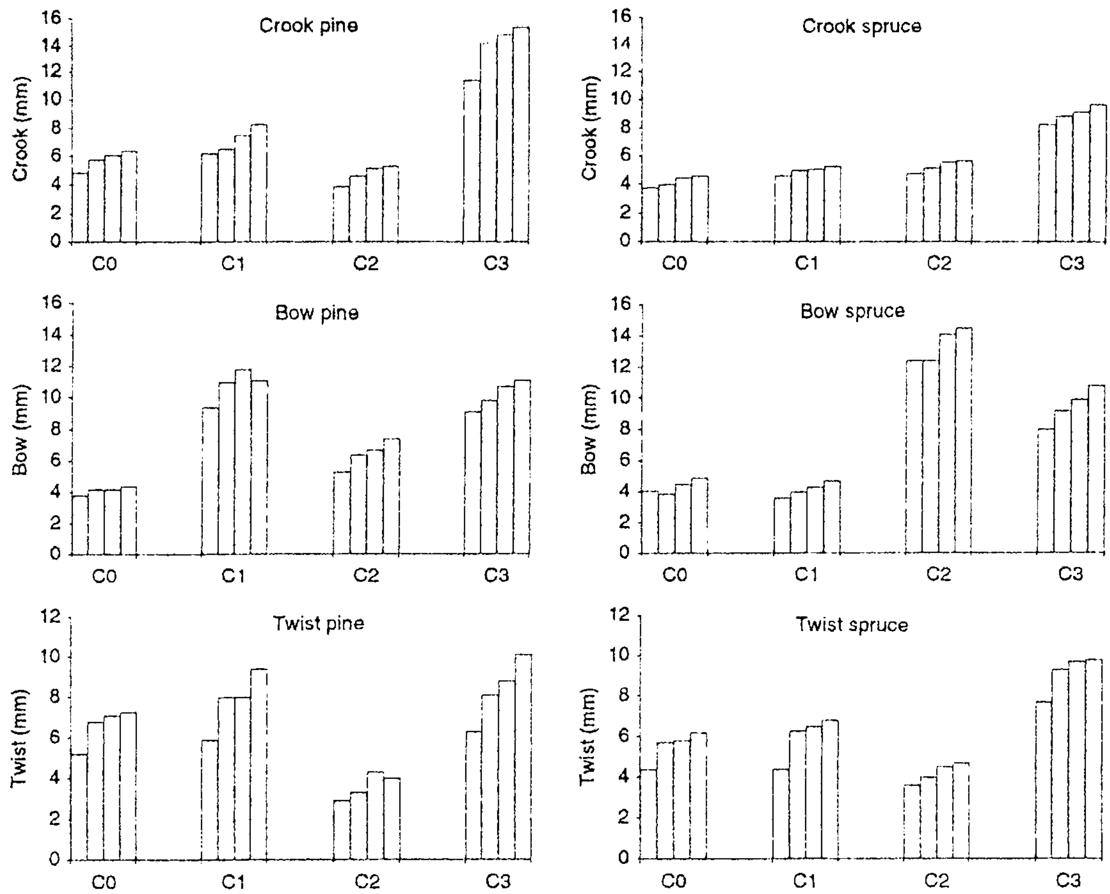


Fig. 8. Influence of compression wood on warp according to four levels Co-C3 of compression wood (A-D see Fig. 6)
Bild 8. Einfluß des Druckholzes auf die Verwerfung für vier Klassen (Co-C3) von Druckholzanteilen (A-D vgl. Bild 6)

low (3–4 boards), which means that too far-reaching conclusions should not be drawn for a separate level.

The effect of compression wood on bow was more pronounced than on crook and twist (see Figure 8). For both pine and spruce, boards with compression wood (levels C1–C3 as one test group) have significantly more bow than boards without compression wood. A significant difference regarding crook and twist was found in spruce, where the amount of crook and twist in level C3 were higher than in the other groups.

3.5
Cracks

The results from crack measuring are presented as the relative crack length, and the ratio between the total length of the cracks and the length of the board for both pine and spruce. The boards are divided into four groups with regard to annual ring orientation and the distance between the pith and boards. The four groups are:

A Boards with pith enclosed in the cross section in all of, or in the part of the length. This group includes the same boards as in group A, previously described in section 3.3.

E Boards sawn at a distance less than 30 mm between the pith and any part of the board. In this group the annual ring orientation varied from 0 to 90 degrees. Boards in group A are not included in this group.

F Boards sawn at a distance greater than 30 mm between the pith and any part of the board. The annual ring orientation in the boards from this group was between 0 and 60 degrees.

G Boards sawn at a distance greater than 30 mm between the pith and any part of the board. The boards in this group have vertical annual rings, i.e. 60 to 90 degrees.

3.5.1
Presence of cracks and relative crack length in the boards

Figure 9 shows, the relative length of cracks before and after the wetting cycles. The influence of pith and juvenile wood on crack length in the boards is obvious. Boards sawn at a distance greater than 30 mm from the pith (groups F and G) have significantly lower crack lengths than boards sawn nearer the pith. This applies to both pine and spruce. Between groups A and E, and groups F and G, there is no significant difference regarding crack length. Between pine and spruce, differences regarding crack length was significant only for group F.

As shown in Figure 10, the proportion of boards without cracks relative to the total number of boards in each group is higher for spruce than for pine. This was probably due to the higher density of pine.

Pine has a greater tendency to form new cracks than spruce when the boards are exposed to cycles of wetting and drying. After the wetting cycles, spruce has almost the same proportion of boards without cracks as it had before (see Figure 10). It should be noted that none of the boards with the pith enclosed in the cross section have been dried without cracks (see group A in Figure 10). Furthermore, the amount of boards with cracks was 3–4 times greater in

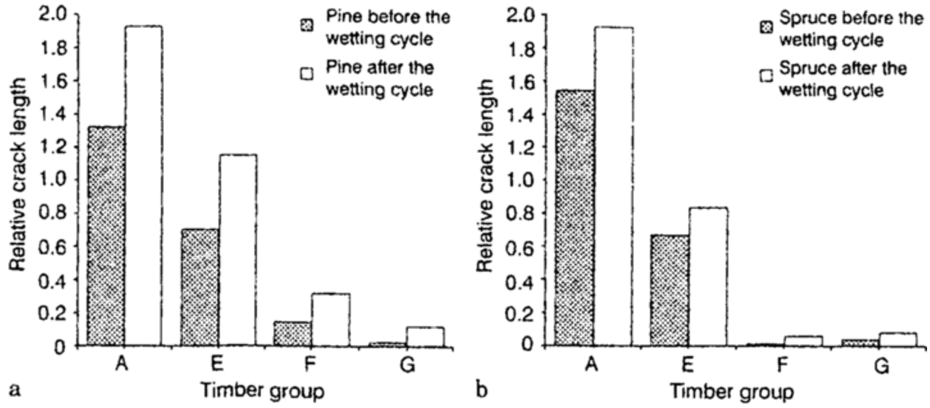


Fig. 9a and b. The relative length of cracks before and after the wetting cycles. The boards are divided into four groups (A, E, F, G) according to annual ring orientation and the distance between the pith and the board; (a) pine, (b) spruce
Bild 9a und b. Relative Rißlänge vor und nach den Feuchtezyklen. Die Bretter waren in 4 Klassen (A, E, F, G) eingeteilt je nach Jahrring-Orientierung und Abstand zwischen Markröhre und Brett; (a) Kiefer; (b) Fichte

boards sawn near the pith (group E) than in boards sawn away from the pith (groups F and G).

3.5.2
The influence of pith on crack formation

The previous analysis of cracks was based on a board as a unit. Here each surface will be examined separately. Figure 11 shows the crack length for pith surfaces versus non-pith surfaces and the changes regarding crack length during the wetting cycles. The pith surface means that the surface (or surfaces) of the board was oriented towards the pith. The boards in group A are excluded in the analysis as these boards do not have pith surfaces. In both pine and spruce, where boards from groups E, F and G have been analysed as one group, the pith surfaces show crack lengths that are significantly higher compared to other surfaces. This applies both before and after the wetting cycles. Homogeneity tests show that pith surfaces tend to crack to a larger extent than other surfaces. It should be noted that the development of cracks on the bark surface in boards with horizontal annual rings during drying is common, especially when the annual ring curvature are small, i.e. the boards are sawn near the pith.

When the crack lengths of each group (E–G) are analyzed separately, the variation makes it difficult to draw any distinct conclusions. However, spruce in group E had significantly higher crack lengths on the pith surfaces, both before and after wetting (see Figure 11). The increase of crack length during wetting was also higher on the pith surfaces. Pine did not show these results. This may be a result of the trend for pine to crack more easily than spruce, and that the cracks initiated on the pith surfaces in pine develop into the adjoining surfaces, especially when the pith is located close to the edge between two surfaces.

Spruce boards sawn at a distance greater than 30 mm from the pith (groups F and G) did not show any difference in crack length between the surfaces. Pine in group F, on the other hand, had a pith surface with greater crack length before the wetting cycles, and in group G both before and after the wetting cycles. The development of cracks in pine, group F, also indicates that cracks initiated of the pith surfaces may propagate to other surfaces during the wetting cycles.

The distinct difference in crack length on spruce pith surfaces between boards sawn at a distance of less and greater than 30 mm from the pith indicates that the pith with the surrounding juvenile wood has a great influence on the proportion of cracks in sawn timber.

In pine, the influence of pith and juvenile wood on the proportion of cracks ranges over a greater distance from the pith compared to spruce. Thus, in pine, the difference in crack length between boards sawn at a distance greater, or less than 30 mm from the pith, is not as clear as in spruce.

3.5.3
Influence of other factors on crack propagation

The influence of the annual ring orientation on crack formation was also investigated on both wet and non-wetted surfaces. Crack formation in the boards was not dependent on annual ring orientation.

For pine and spruce the mean value of moisture content at the end of each wetting cycle was lower than that at the beginning of the test (see Figure 5). Decrease of the moisture content may result in an increase of cracks in the boards when compared to a constant moisture content at the end of each cycle.

4
Conclusions

The results show that if boards are sawn radially from the log, without pith and juvenile wood, properties are obtained which are better than those of conventionally sawn timber.

Warp in terms of crook, bow, twist and cup as well as number of cracks in sawn timber from both pine and

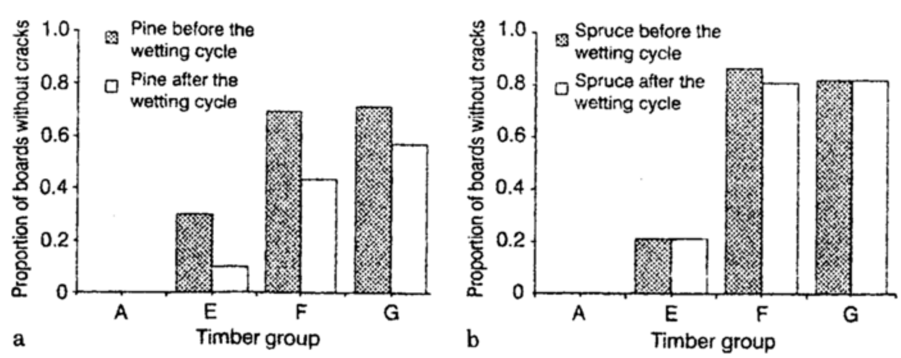


Fig. 10a and b. The proportion of boards without cracks, related to the total number of boards in each group. The boards are divided into four groups (A, E, F, G) according to the annual ring orientation and the distance between pith and the board; (a) pine; (b) spruce
Bild 10a und b. Anteil der Bretter ohne Risse. Die Bretter waren in 4 Klassen (A, E, F, G) eingeteilt je nach Jahrring-Orientierung und Abstand zwischen Markröhre und Brett; (a) Kiefer; (b) Fichte

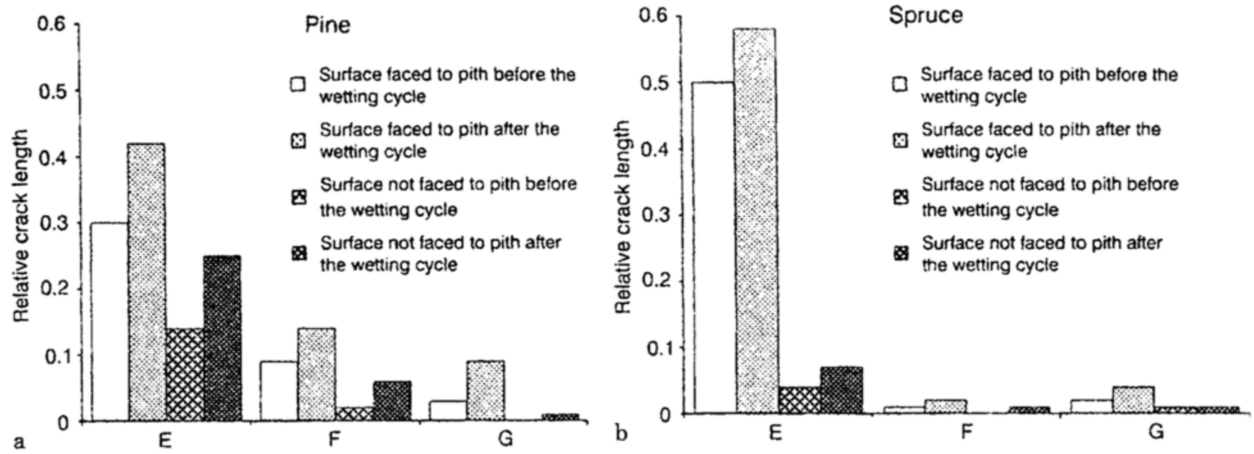


Fig. 11a and b. Crack length for pith surfaces contra non-pith surfaces. The boards are divided into three groups (E, F, G) according to annual ring orientation and the distance between the pith and the board; (a) pine; (b) spruce

Bild 11a und b. Vergleich der Rißlänge bei Brettern mit und ohne sichtbar Markröhre and der Oberfläche. Die Bretter waren in 3 Klassen (E, F, G) eingeteilt je nach Jahrring-Orientierung und Abstand zwischen Markröhre und Brett; (a) Kiefer; (b) Fichte

spruce increase when timber is exposed to repeated cycles of wetting and drying. Warp increases in each wetting cycle. The greatest increase occurs after the first cycle.

The influence of annual ring orientation on warp, except for cup, was not clear. Generally, the boards with semi-vertical and vertical annual rings have lower mean values for warp than boards with horizontal annual rings and boards with the pith enclosed. As a consequence of the great variation in warp, it was difficult to detect any significant (confidence 0.95) differences between boards with different annual ring orientations. Where differences in warp were found, the warp was significantly lower in boards with semi-vertical and vertical annual rings.

Cup is greatly influenced by the curvature of the annual rings as a consequence of the anisotropic nature of wood. This means that boards with horizontal annual rings, sawn near the pith, have the greatest cup. Consequently, boards with vertical annual rings show no cup.

Compression wood has the greatest influence on the increase of warp. Bow is more sensitive to compression wood than crook and twist.

This study, however, demonstrates that the number of cracks in boards was clearly related to the juvenile wood and the distance from the pith in sawn timber. The number of boards with cracks was 3 to 4 times greater in timber sawn near the pith, that is when the distance between the board and the pith was less than 30 mm, compared to timber sawn further away from the pith. When the boards were exposed to wetting and drying cycles, the number of boards with cracks increased in both pine and spruce. The relative crack length in boards sawn near the pith was greater than in boards sawn away from the pith. During wetting and drying, the crack length increases regardless of the location of the board in relation to the pith.

When the four surfaces of the board were examined separately the results show that pith surfaces have greater relative crack lengths and a greater tendency to crack than the other surfaces, especially when the boards are sawn near the pith.

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